ESD-TR-65-10

PREDICTION IN THE STRATOSPHERE

Frederick P. Ostby, Jr.
Keith W. Veigas
Bernard J. Erickson

June 1965

ESSW

433L SYSTEM PROGRAM OFFICE
ELECTRONICS SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
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FOREWORD

System 433L; project 2.0; task 2.2. This TR has been prepared for United Aircraft Corporation, East Hartford, Conn., under Subcontract no. 15107 to Contract no. AF 19(628)-3437, by The Travelers Research Center, Inc., 250 Constitution Plaza, Hartford, Conn. The Research Center's publication number is 7463-170. Victor K. Syphers, Lt. Colonel, USAF, is Acting System Program Director. Submitted for approval on 25 May, 1965.

ABSTRACT

This report describes a base technique for the 24- and 48-hr prediction of stratospheric contour height changes in winter at 100, 50, and 30 mb. On independent data, this technique yields superior results to persistence at all three levels and for both forecast intervals. Prediction equations are derived by applying the screening regression technique to atmospheric variables at a network of grid points surrounding a predicand point. Incorporation of predictors, based on perfect prognoses at lower levels, brings about a significant improvement in the results. Some improvement is also noted when a geographical stratification is employed. However, orientation of the grid network with the flow pattern did not result in any substantial improvement.

REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Victor K. Syphers

Victor K. Syphers
Lt. Colonel, USAF
Acting System Program Director

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SECTION I

INTRODUCTION

The objective of this study is to demonstrate the feasibility of stratospheric prediction by developing a physical-statistical base technique to forecast 100-, 50-, and 30-mb heights for 24- and 48-hr periods.

Previous work in this area was aimed at developing regression equations based on middle- and upper-tropospheric prognoses to extrapolate upward to derive temperatures, winds, and heights at stratospheric levels [6]. The results of this earlier test were not positive and demonstrated the need for a technique superior to persistence. It was suggested at the time that a technique using a more direct approach instead of the vertical-extrapolation equations should be investigated.

The framework of the present study called for a rather modest effort. The experimental design required a minimum amount of sophistication and a restricted geographical application. The so-called "persistence" technique was used as a control to demonstrate the feasibility of more extensive and elaborate investigations.

SECTION II

DATA PROCESSING

Hemispheric grid-point data, provided by the Air Force Global Weather Central (GWC) and containing heights at six constant pressure levels determined twice daily for December 1963 and January and February 1964, were available for this study.

The area chosen for feasibility testing is shown in Fig. 1. The 48 predictand points within the area are located at every other Joint Numerical Weather Prediction (JNWP) grid point.

Selection of cases was limited to the 81 consecutive map times extending from 0000 GMT, 1 December 1963 to 0000 GMT, 12 January 1964, yielding 3888 cases (48 cases per map time). Of these, 16 maps (768 cases) were made available for independent-data verification by withholding the data of every fifth map time, leaving a sample of 3120 cases for development work.

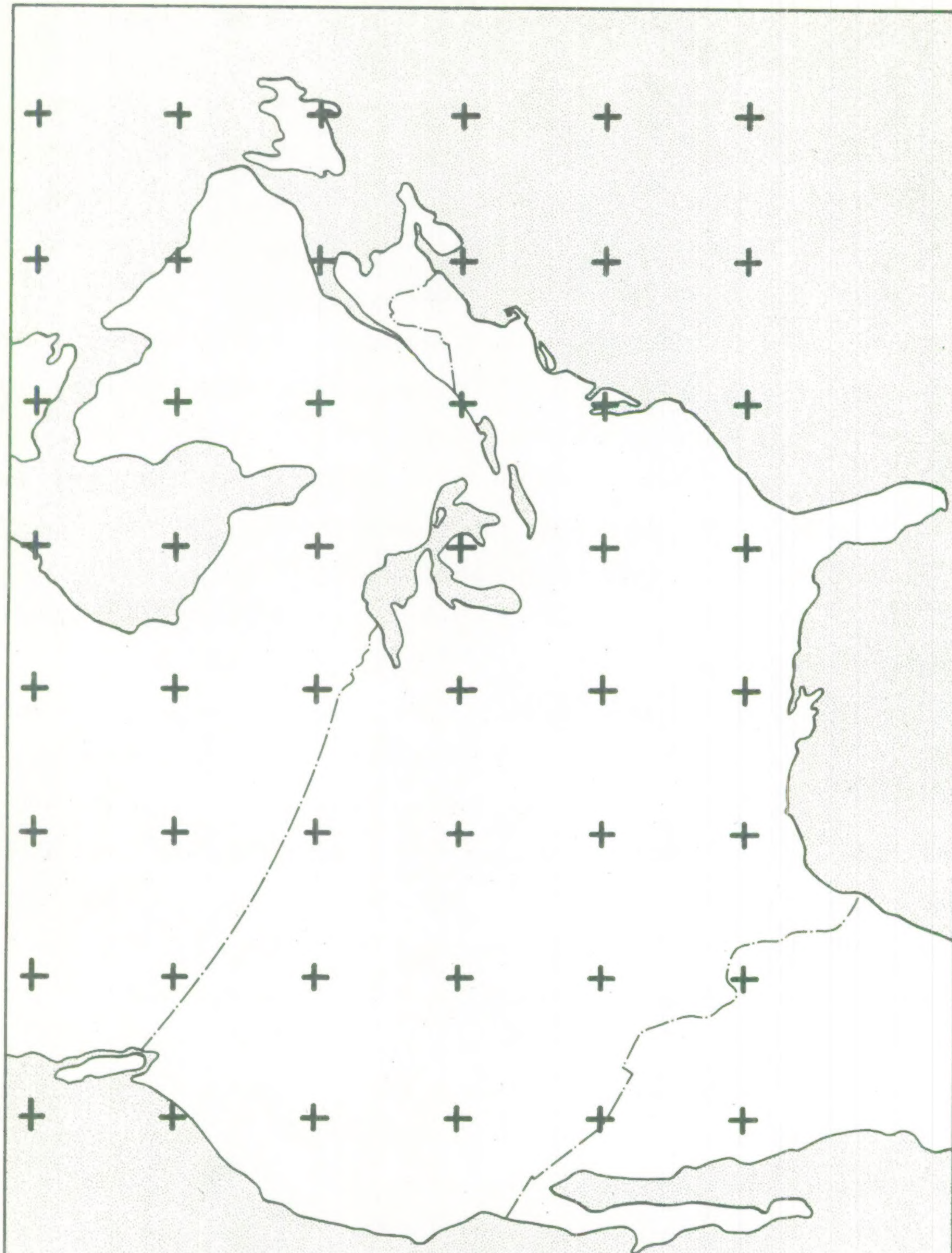

Fig. 1. Area used for feasibility tests. Grid points shown are predictand points.

SECTION III

THE PREDICTION TECHNIQUE

1. The Composite Grid

A grid for extracting predictor information surrounding any predictand point was constructed so that the grid would measure variables at locations relative to a predictand point rather than at fixed geographical locations (See Fig. 2). The grid point defined by the (K,L)-location (3,3) is placed over the predictand point, and the grid is oriented so that the line K=3 coincides with the meridian passing through the predictand point. For development work, grid placement and data tabulation were done by computer programs, and "analyzed maps" were on magnetic tape (an option in the computer program permits the employment of an alternative grid orientation — that is, with respect to the 100-mb flow rather than to north-south). On a polar stereographic projection with standard parallel at 60°N, the 5 × 5 array forms a set of evenly-spaced points with the grid interval being equivalent to two JNWP grid intervals (762 km at 60°N). The 25 points defined by this grid system were the ones used for basic predictor tabulation.

2. Screening Regression

The screening procedure suggested by Bryan [1] and developed for the IBM 704 electronic computer by Miller [3, 4] was used to screen the possible predictors identified in subsequent sections (this program has also been written for the IBM 7094). One who designs a statistical prediction experiment invariably likes to consider all predictors deemed important on the basis of previous theoretical, synoptic, and empirical work, but as Lorenz [2] points out, a prediction equation should contain few predictors in comparison with the size of the developmental sample; if there are too many, a relationship that fits the sample used to establish it is likely to fail when applied to a new sample. The object of the screening procedure is to select from a set of possible predictors the subset that most significantly and independently contributes to reducing the variance of the predictand.

From an array of possible predictors, the screening procedure first selects the one that has the highest linear correlation with the predictand in question. This predictor is then held constant and partial-correlation coefficients between the predictand and each of the remaining predictors are examined; the predictor now associated with the highest coefficient is the second one selected. Additional predictors

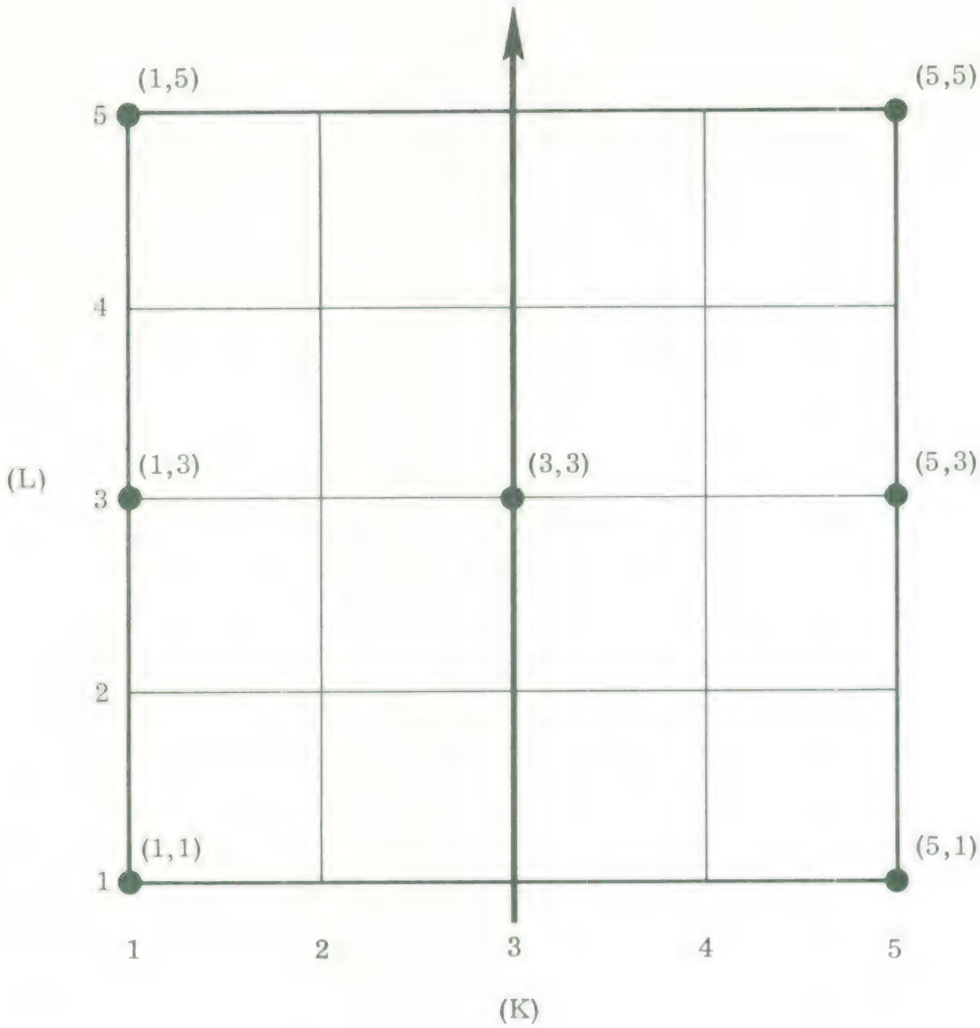

Fig. 2. Composite grid overlay. Predictand point is at K=3, L=3. Predictor points are circled.

are chosen similarly. Selection is halted whenever a predictor fails to pass a significance test. After the significant predictors have been selected, the regression coefficients are obtained by the method of least squares.

The criterion of significance, as applied to the screening procedure, is not clear-cut because the usual F-test methods (e.g., [5]) are not applicable [4]. If a predictor is chosen at random from a group of predictors, an F-test is usually taken at the 95% level; this allows a 1-in-20 chance of considering the predictor significant when, in fact, it is not. Because the screening procedure does not select predictors randomly, a more severe test is needed to specify a 1-in-20 chance. For his screening procedure, Miller [4] suggested that the critical F-value be a function of the number of possible predictors. The F-test was used in this form in these experiments.

3. Predictands

Height changes at 100, 50, and 30 mb for forecast intervals of 24 and 48 hr were chosen as predictands for the study. The predictand list is shown in Table I.

4. Predictors Considered

The GWC hemispheric grid-point data were used as the primary source of predictor data. Special preprocessing programs automatically derived 5×5 grid-point arrays of height and thickness data for each predictand point in the developmental sample. In addition, various vorticity terms were computed at the predictand point by conventional finite-difference procedures. The list of 570 possible predictors is given in Table II.

Because Miller's screening-regression technique (as programmed for the IBM 7094) has an upper limit of 180 predictors which can be examined simultaneously, the number of possible predictors had to be reduced subjectively before screening regression was applied.

TABLE I
LIST OF PREDICTANDS

Symbol	Description
$\Delta\hat{Z}_{100}$ (24)	24-hr forecast 100-mb height change*
$\Delta\hat{Z}_{50}$ (24)	24-hr forecast 50-mb height change*
$\Delta\hat{Z}_{30}$ (24)	24-hr forecast 30-mb height change*
$\Delta\hat{Z}_{100}$ (48)	48-hr forecast 100-mb height change*
$\Delta\hat{Z}_{50}$ (48)	48-hr forecast 50-mb height change*
$\Delta\hat{Z}_{30}$ (48)	48-hr forecast 30-mb height change*

*Unit of measure = 10 ft.

SECTION IV

PREDICTION EXPERIMENTS

A series of experiments was formulated to examine various alternative approaches to stratospheric prediction within the limitations of the feasibility study. The initial experiment consisted of orienting our grid system north-south, applying it over the entire predictand area (no stratification), and using only predictors from Table II which did not incorporate prognostic information. This was our "base-technique" experiment. Subsequent experiments were devised to determine the advantages of incorporating lower-level prognostic-type predictors, orienting the grid system with respect to the flow pattern, and developing a simple geographical stratification scheme. With the exception of the incorporation of prognoses, all experiments used the same set of possible predictors from the list in Table II.

Because the number of possible predictors exceeded the screening program's limit of 180, it was necessary to subjectively reduce the predictor list before screening. In this study, the reduction was accomplished by considering seven predictors in each subset of 25. These seven points are shown on the grid overlay in Fig. 2. Other combinations of predictors were not attempted in these initial experiments. The types of experiments performed are outlined in Table III.

TABLE II
POSSIBLE PREDICTORS

Symbol	Description
Z_{500}	500-mb height*
Z_{300}	300-mb height*
Z_{200}	200-mb height*
Z_{100}	100-mb height*
Z_{50}	50-mb height*
Z_{30}	30-mb height*
ΔZ_{500}	12-hr 500-mb height change*
ΔZ_{300}	12-hr 300-mb height change*
ΔZ_{200}	12-hr 200-mb height change*
ΔZ_{100}	12-hr 100-mb height change*
ΔZ_{50}	12-hr 50-mb height change*
ΔZ_{30}	12-hr 30-mb height change*
$H_{500-300}$	500- to 300-mb thickness*
$H_{200-100}$	200- to 100-mb thickness*
H_{100-30}	100- to 30-mb thickness*
$\Delta H_{500-300}$	12-hr 500- to 300-mb thickness change*
$\Delta H_{200-100}$	12-hr 200- to 100-mb thickness change*
ΔH_{100-30}	12-hr 100- to 30-mb thickness change*

*Unit of measure is 10 ft; number available is 25.

TABLE II (cont'd)

Symbol	Description
ΔZ_{500} (24)	24-hr forecast 500-mb height change*
ΔZ_{200} (24)	24-hr forecast 200-mb height change*
ΔZ_{500} (48)	48-hr forecast 500-mb height change*
ΔZ_{200} (48)	48-hr forecast 200-mb height change*
η_{500}	500- mb absolute vorticity†
η_{300}	300-mb absolute vorticity†
η_{200}	200-mb absolute vorticity†
η_{100}	100-mb absolute vorticity†
η_{50}	50-mb absolute vorticity†
η_{30}	30-mb absolute vorticity†
$\Delta\eta_{500}$	12-hr 500-mb vorticity change†
$\Delta\eta_{300}$	12-hr 300-mb vorticity change†
$\Delta\eta_{200}$	12-hr 200-mb vorticity change†
$\Delta\eta_{100}$	12-hr 100-mb vorticity change†
$\Delta\eta_{50}$	12-hr 50-mb vorticity change†
$\Delta\eta_{30}$	12-hr 30-mb vorticity change†
$\zeta T_{500-300}$	500- to 300-mb thermal vorticity†
$\zeta T_{200-100}$	200- to 100-mb thermal vorticity†

*Unit of measure = 10 ft; number available = 25.
†Unit of measure = 10^{-5} sec^{-1}; number available = 1.

TABLE II (cont'd)

Symbol	Description
ζT_{100-30}	100- to 30-mb thermal vorticity†
$\Delta\zeta T_{500-300}$	12-hr 500- to 300-mb thermal vorticity change†
$\Delta\zeta T_{200-100}$	12-hr 200- to 100-mb thermal vorticity change†
$\Delta\zeta T_{100-30}$	12-hr 100- to 30-mb thermal vorticity change†
V	Magnitude of 100-mb geostrophic wind‡
V^2	Square of magnitude of 100-mb geostrophic wind¶

†Unit of measure = 10^{-5} sec^{-1}; number available = 1.
‡Unit of measure = knots; number available = 1.
¶Unit of measure = $(knots)^2$; number available = 1.

TABLE III
STRATOSPHERIC PREDICTION EXPERIMENTS

Exp. no.	Grid orientation	Predictors	Stratification
1	North-south	No prognoses	Unstratified
2	North-south	With prognoses	Unstratified
3	Flow	No prognoses	Unstratified
4	Flow	With prognoses	Unstratified
5	North-south	No prognoses	Stratified
6	North-south	With prognoses	Stratified

SECTION V

RESULTS

In all of the experiments described in this section, the screening regression technique was applied to 3120 cases to develop prediction equations for 24- and 48-hr height changes at 100, 50, and 30 mb. These equations were then applied to the 768 cases which comprised the independent data sample (the various equations can be found in the appendix).

5. Experiment 1

In this experiment, the grid is oriented north-south. There is no stratification and the possible predictors listed in Table II (excluding lower-level prognostic predictors) are used to derive regression equations. Table IV lists the predictors in the order of their selection by the screening procedure, and the percentage of the total variance explained by each. The predictor symbols are defined in Table II and the accompanying numbers refer to the (K,L)-predictor locations in the grid system shown in Fig. 2.

From Table IV it can be seen that the first predictor selected is usually the 12-hr height change "upstream" for the particular level in question. This grid point is two grid intervals to the west of the predictand point. The only exception is the 24-hr, 30-mb height change forecast ($\Delta\hat{Z}_{30}$), where the first predictor selected is the 12-hr, 50-mb height change located at the predictand point (3,3).

6. Experiment 2

This experiment considers the addition of 500- and 200-mb height prognoses as possible predictors. The reason for this kind of test is that, for operational purposes, one may have available a good set of mid-tropospheric and lower-stratospheric dynamic prognoses which could be used for predictive information. In these particular tests, it must be kept in mind that we have used actual analyses (perfect prognoses); one must still examine the problem of how much skill is lost in going from a perfect prognosis to an operational prognosis.

TABLE IV

PREDICTORS SELECTED BY SCREENING REGRESSION FOR EXP. 1

(north-south orientation, no prognoses, unstratified)

(a) 24-hr forecast interval

Order of selection	$\Delta\hat{Z}_{100}$		$\Delta\hat{Z}_{50}$		$\Delta\hat{Z}_{30}$	
	predictor	% reduction	predictor	% reduction	predictor	% reduction
1	$\Delta Z_{100}(1, 3)$	23.4	$\Delta Z_{50}(1, 3)$	22.3	$\Delta Z_{50}(3, 3)$	21.6
2	$\Delta Z_{500}(3, 3)$	5.6	$\Delta Z_{100}(3, 3)$	5.0	$\Delta Z_{30}(1, 3)$	5.9
3	$\Delta\eta_{500}(3, 3)$	1.7	$\Delta H_{100\text{-}30}(3, 3)$	2.9	$H_{100\text{-}30}(3, 3)$	2.9
4	$H_{200\text{-}100}(5, 5)$	1.6	$\Delta Z_{30}(1, 5)$	1.9	$H_{200\text{-}100}(3, 3)$	2.5
5	$\xi T_{100\text{-}30}(3, 3)$	1.5	$H_{200\text{-}100}(5, 5)$	1.7	$\Delta\eta_{50}(3, 3)$	1.6
6	$\Delta Z_{30}(1, 5)$	1.2	$\Delta\eta_{50}(3, 3)$	1.5	$\Delta\eta_{30}(3, 3)$	1.3
7	$H_{200\text{-}100}(1, 1)$	1.0	$\Delta Z_{500}(1, 5)$	0.9	$H_{100\text{-}30}(1, 5)$	1.1
8	$Z_{100}(3, 3)$	1.2	$Z_{500}(1, 1)$	0.8	$\Delta Z_{50}(1, 3)$	0.8
9	$Z_{100}(1, 3)$	1.8	$Z_{50}(3, 3)$	1.7	$Z_{50}(5, 5)$	0.7
10	$Z_{30}(5, 1)$	1.4	$Z_{30}(5, 1)$	0.8	$Z_{30}(5, 1)$	2.4
11	$\Delta Z_{50}(3, 3)$	1.4	$Z_{30}(1, 5)$	1.7	$Z_{50}(5, 1)$	1.0
12	$Z_{500}(5, 3)$	1.0	$Z_{500}(1, 5)$	0.9	$\eta_{50}(3, 3)$	0.9
13	$Z_{50}(3, 3)$	0.7	$H_{500\text{-}300}(1, 5)$	0.7	$Z_{100}(3, 3)$	1.7
14	—	—	$\Delta\eta_{30}(3, 3)$	0.7	—	—
15	—	—	$\Delta\xi T_{100\text{-}30}(3, 3)$	0.4	—	—
16	—	—	$\Delta Z_{50}(1, 1)$	0.2	—	—
17	—	—	$\Delta Z_{30}(1, 3)$	0.3	—	—
18	—	—	$H_{100\text{-}30}(5, 3)$	0.3	—	—
19	—	—	$Z_{30}(1, 3)$	0.5	—	—
Total	—	43.5	—	45.2	—	44.4

TABLE IV (cont'd)

(b) 48-hr forecast interval

Order of selection	$\Delta\hat{Z}_{100}$		$\Delta\hat{Z}_{50}$		$\Delta\hat{Z}_{30}$	
	predictor	% reduction	predictor	% reduction	predictor	% reduction
1	$\Delta Z_{100}(1, 3)$	17.5	$\Delta Z_{50}(1, 3)$	17.7	$\Delta Z_{30}(1, 3)$	19.9
2	$\Delta Z_{50}(1, 5)$	3.1	$\Delta Z_{30}(1, 5)$	6.4	$H_{100\text{-}30}(3, 3)$	8.5
3	$H_{200\text{-}100}(1, 5)$	2.8	$H_{100\text{-}30}(1, 3)$	4.4	$\Delta Z_{30}(1, 5)$	3.1
4	$Z_{100}(3, 3)$	1.2	$Z_{50}(5, 5)$	2.4	$\Delta Z_{50}(3, 3)$	2.5
5	$\eta_{30}(3, 3)$	7.7	$Z_{200}(1, 1)$	2.0	$Z_{50}(5, 5)$	1.9
6	$H_{500\text{-}300}(1, 5)$	3.3	$Z_{50}(3, 3)$	1.9	$Z_{100}(1, 1)$	2.2
7	$Z_{50}(1, 1)$	2.5	$Z_{30}(5, 1)$	1.5	$Z_{200}(3, 3)$	2.4
8	$H_{100\text{-}300}(5, 1)$	1.4	$Z_{50}(1, 5)$	2.8	$Z_{30}(5, 1)$	1.3
9	$Z_{500}(5, 3)$	0.8	$Z_{500}(1, 5)$	2.4	$H_{100\text{-}30}(1, 5)$	2.4
10	$\Delta Z_{200}(3, 3)$	1.4	$H_{200\text{-}100}(1, 5)$	2.1	$Z_{50}(5, 1)$	1.4
11	$Z_{500}(1, 1)$	1.1	—	—	$\eta_{200}(3, 3)$	1.2
12	$\Delta Z_{50}(1, 1)$	0.7	—	—	$H_{500\text{-}300}(1, 5)$	0.7
13	$\Delta H_{200\text{-}100}(1, 3)$	0.4	—	—	$Z_{300}\ (1, 5)$	2.1
14	$Z_{300}\ (1, 5)$	0.4	—	—	$Z_{50}\ (1, 3)$	0.8
15	$Z_{30}\ (1, 3)$	0.4	—	—	$\Delta\eta_{50}\ (3, 3)$	0.5
16	$H_{100\text{-}30}\ (5, 5)$	0.4	—	—	—	—
17	$Z_{300}\ (3, 3)$	0.4	—	—	—	—
18	$Z_{50}\ (3, 3)$	0.4	—	—	—	—
19	$Z_{200}\ (1, 5)$	0.4	—	—	—	—
20	$H_{100\text{-}30}\ (3, 3)$	0.5	—	—	—	—
Total	—	46.8	—	43.6	—	50.9

The first predictors selected in this experiment were the 24- and 48-hr, 200-mb prognostic heights at the predictand point for the 24- and 48-hr, 100-mb height prediction, respectively (see Table V). At 50 mb, the first predictors selected are the same as in Exp. 1, with the prognostic predictors being selected second. At 30 mb, the 24-hr prediction equation does not select a prognostic predictor until after five predictors, based on observed data, have been chosen, while for the 48-hr prediction the third predictor selected is a prognostic one. It is reasonable to expect the 500- and 200-mb prognostic predictors to make a more significant contribution at the lowest (100-mb) level. The total percent reduction of variance (PR) for this experiment is higher for each of the six predictands than the corresponding predictands of Exp. 1, with the difference decreasing with increasing height.

7. Experiment 3

The same set of possible predictors used in Exp. 1 was used in this experiment. The only difference was in the selection of grid orientation. Whereas predictors in Exp. 1 were derived in a north-south grid orientation, the grid for this experiment was oriented so that a line defined by K = 3 (see Fig. 2) was normal to the 100-mb geostrophic wind computed at the predictand point. The predictors in their order of selection are shown in Table VI. Note that the first predictor selected corresponds to that of Exp. 1 (Table IV) for all six predictands. However, although the coordinate locations are the same, the geographical locations differ because of the difference in grid orietation. While the percent reduction of variance attributed to these flow-oriented first predictors is greater for each of the six predictands, the total PR is only greater for one of them — the 24-hr, 100-mb height change.

8. Experiment 4

For this experiment, the grid is oriented with the flow and the predictor list is expanded to include 500- and 200-mb prognoses. The results of applying the screening procedure are shown in Table VII. Comparison with Exp. 2 (Table V), where the predictor list is the same but the orientation is different, shows that here, too, one selects the same predictor first for all six predictands. There is very little difference between the two experiments (2 and 4) in the PR for the first selected predictors, the flow-orientation PR was generally higher, although the total PR for all six predictands was higher for the north-south orientation.

TABLE V
PREDICTORS SELECTED BY SCREENING REGRESSION FOR EXP. 2
(north-south orientation, with prognoses, unstratified)

(a) 24-hr forecast interval

Order of selection	$\Delta\hat{Z}_{100}$		$\Delta\hat{Z}_{50}$		$\Delta\hat{Z}_{30}$	
	predictor	% reduction	predictor	% reduction	predictor	% reduction
1	$\Delta Z_{200}(24)$ (3, 3)	56.6	ΔZ_{50} (1, 3)	22.3	ΔZ_{50} (3, 3)	21.6
2	ΔZ_{50} (1, 3)	6.3	$\Delta Z_{200}(24)$ (3, 3)	8.3	ΔZ_{30} (1, 3)	5.9
3	$H_{200-100}$ (3, 3)	3.6	ΔZ_{30} (3, 3)	5.2	H_{100-30} (3, 3)	2.9
4	$H_{200-100}$ (1, 3)	2.4	H_{100-30} (3, 3)	3.5	$H_{200-100}$ (3, 3)	2.5
5	H_{100-30} (3, 3)	1.5	$\Delta Z_{200}(24)$ (5, 3)	2.6	$\Delta\eta_{50}$ (3, 3)	1.6
6	H_{100-30} (1, 3)	1.7	ΔH_{100-30} (1, 5)	1.8	$\Delta Z_{200}(24)$ (3, 3)	1.5
7	ΔZ_{50} (3, 3)	1.4	$\Delta\eta_{50}$ (3, 3)	1.3	H_{100-30} (1, 5)	2.0
8	$\Delta Z_{200}(24)$ (5, 3)	0.6	ΔZ_{30} (1, 3)	0.9	$\Delta\eta_{30}$ (3, 3)	1.1
9	H_{100-30} (5, 5)	0.5	$\Delta Z_{200}(24)$ (5, 5)	0.7	Z_{50} (5, 5)	1.0
10	ΔH_{100-30} (1, 5)	0.5	$\Delta Z_{500}(24)$ (5, 1)	0.7	Z_{30} (5, 1)	2.5
11	$\Delta\eta_{50}$ (3, 3)	0.3	$H_{200-100}$ (1, 3)	0.5	$\Delta Z_{500}(24)$ (5, 1)	1.0
12	$\Delta Z_{200}(24)$ (1, 1)	0.3	Z_{500} (1, 1)	0.6	Z_{500} (3, 3)	1.1
13	$\Delta Z_{500}(24)$ (5, 1)	0.4	Z_{50} (3, 3)	1.2	η_{300} (3, 3)	0.8
14	ΔZ_{500} (1, 1)	0.3	$H_{500-300}$ (3, 3)	1.4	Z_{50} (5, 1)	0.7
15	ΔZ_{500} (3, 3)	0.3	$\Delta Z_{500}(24)$ (1, 1)	1.2	$H_{200-100}$ (1, 3)	0.8
16	$H_{500-300}$ (1, 5)	0.2	Z_{50} (1, 5)	0.7	$\Delta Z_{500}(24)$ (1, 1)	0.6
17	Z_{500} (1, 5)	0.5	Z_{30} (5, 1)	1.3	Z_{500} (1, 1)	0.8
18	Z_{500} (3, 3)	0.3	Z_{500} (1, 5)	1.1	$\Delta Z_{500}(24)$ (5, 3)	0.6
19	Z_{50} (1, 5)	0.8	$\Delta\eta_{30}$ (3, 3)	0.4	ΔZ_{100} (5, 5)	0.6
20	—	—	$H_{200-100}$ (1, 5)	0.4	ΔZ_{500} (5, 3)	0.4
Total	—	78.5	—	56.1	—	50.0

TABLE V (cont'd)

(b) 48-hr forecast interval

Order of selection	$\Delta\hat{Z}_{100}$		$\Delta\hat{Z}_{50}$		$\Delta\hat{Z}_{30}$	
	predictor	% reduction	predictor	% reduction	predictor	% reduction
1	$\Delta Z_{200}(48)$ (3, 3)	64.9	ΔZ_{50} (1, 3)	17.7	ΔZ_{30} (1, 3)	19.9
2	$H_{200-100}$ (3, 3)	6.7	$\Delta Z_{200}(48)$ (3, 3)	13.4	H_{100-30} (3, 3)	8.5
3	ΔZ_{50} (1, 5)	3.4	H_{100-30} (3, 3)	7.0	$\Delta Z_{200}(48)$ (3, 3)	5.9
4	$\Delta Z_{200}(48)$ (5, 3)	2.7	ΔZ_{30} (1, 5)	5.1	ΔH_{100-30} (1, 5)	3.8
5	ΔZ_{50} (1, 3)	1.2	$\Delta Z_{200}(48)$ (5, 3)	4.3	ΔZ_{50} (3, 3)	3.2
6	$H_{200-100}$ (1, 3)	1.0	ΔZ_{30} (1, 3)	1.7	$\Delta Z_{500}(48)$ (5, 1)	2.4
7	H_{100-30} (3, 3)	0.7	$\Delta Z_{500}(48)$ (5, 1)	1.3	Z_{500} (1, 5)	1.8
8	Z_{500} (3, 3)	0.6	$\Delta Z_{500}(24)$ (1, 1)	1.3	$H_{500-300}$ (1, 5)	1.8
9	Z_{300} (1, 3)	0.8	ΔZ_{200} (1, 3)	1.0	Z_{500} (5, 5)	1.2
10	$\Delta Z_{500}(48)$ (3, 3)	0.7	Z_{500} (1, 5)	0.8	Z_{30} (5, 1)	1.5
11	Z_{30} (5, 1)	0.7	Z_{300} (1, 5)	1.8	$\Delta Z_{500}(48)$ (5, 3)	0.9
12	$H_{200-100}$ (1, 5)	0.4	Z_{500} (1, 1)	1.1	$H_{200-100}$ (1, 3)	0.7
13	$H_{500-300}$ (1, 5)	0.5	Z_{50} (3, 3)	1.8	$\Delta Z_{500}(24)$ (1, 1)	0.6
14	Z_{500} (1, 5)	0.3	Z_{50} (5, 1)	0.8	H_{100-30} (1, 1)	1.0
15	$\Delta Z_{500}(48)$ (5, 1)	0.3	Z_{50} (1, 5)	1.7	Z_{50} (5, 3)	1.5
16	$\Delta Z_{500}(24)$ (1, 1)	0.4	$H_{500-300}$ (3, 3)	0.8	H_{100-30} (1, 5)	0.8
17	—	—	Z_{100} (5, 5)	1.1	Z_{500} (3, 3)	1.1
18	—	—	Z_{100} (5, 3)	0.9	ΔZ_{50} (1, 5)	0.7
19	—	—	$H_{200-100}$ (1, 3)	1.0	ΔZ_{50} (5, 3)	0.6
20	—	—	—	—	Z_{50} (5, 1)	0.4
Total	—	85.3	—	64.6	—	58.4

TABLE VI
PREDICTORS SELECTED BY SCREENING REGRESSION FOR EXP. 3
(north-south orientation, no prognoses, unstratified)

(a) 24-hr forecast interval

Order of selection	$\Delta\hat{Z}_{100}$ predictor		$\Delta\hat{Z}_{100}$ % reduction	$\Delta\hat{Z}_{50}$ predictor		$\Delta\hat{Z}_{50}$ % reduction	$\Delta\hat{Z}_{30}$ predictor		$\Delta\hat{Z}_{30}$ % reduction
1	ΔZ_{100}	(1, 3)	26.2	ΔZ_{50}	(1, 3)	24.7	ΔZ_{50}	(3, 3)	21.7
2	ΔZ_{500}	(3, 3)	5.3	ΔZ_{100}	(3, 3)	4.8	ΔZ_{30}	(1, 3)	9.2
3	Z_{30}	(1, 3)	2.6	ΔZ_{30}	(1, 3)	3.0	H_{100-30}	(3, 3)	2.7
4	ΔZ_{30}	(3, 3)	2.1	ΔH_{100-30}	(3, 3)	1.6	$H_{200-100}$	(3, 3)	2.6
5	Z_{30}	(5, 3)	2.0	Z_{30}	(1, 3)	1.8	Z_{30}	(5, 1)	1.3
6	Z_{50}	(3, 3)	1.5	Z_{100}	(5, 1)	2.1	$\Delta\eta_{50}$	(3, 3)	1.2
7	Z_{500}	(5, 5)	1.4	$\Delta\eta_{50}$	(3, 3)	1.3	$\Delta\eta_{30}$	(3, 3)	0.9
8	$\Delta\eta_{500}$	(3, 3)	0.8	Z_{50}	(3, 3)	1.1	Z_{200}	(1, 5)	1.0
9	ΔZ_{50}	(1, 3)	0.7	—		—	ΔZ_{30}	(5, 3)	0.5
10	Z_{100}	(3, 3)	1.0	—		—	ΔZ_{50}	(1, 3)	0.5
11	Z_{300}	(5, 3)	3.4	—		—	Z_{50}	(5, 1)	0.5
12	Z_{500}	(5, 1)	0.9	—		—	H_{100-30}	(1, 5)	0.6
13	$H_{500-300}$	(3, 3)	0.5	—		—	Z_{100}	(3, 3)	0.7
14	$\zeta T_{500-300}$	(3, 3)	0.6	—		—	—		—
15	ΔZ_{200}	(1, 3)	0.5	—		—	—		—
16	Z_{500}	(1, 3)	0.5	—		—	—		—
17	$H_{500-300}$	(1, 5)	0.7	—		—	—		—
Total	—		50.7	—		40.4	—		43.4

TABLE VI (cont'd)

(b) 48-hr forecast interval

Order of selection	$\Delta\hat{Z}_{100}$		$\Delta\hat{Z}_{50}$		$\Delta\hat{Z}_{30}$	
	predictor	% reduction	predictor	% reduction	predictor	% reduction
1	ΔZ_{100} (1, 3)	20.5	ΔZ_{50} (1, 3)	21.3	ΔZ_{30} (1, 3)	22.2
2	$H_{200-100}$ (1, 5)	5.0	H_{100-30} (1, 3)	5.4	H_{100-30} (3, 3)	8.3
3	ΔZ_{50} (1, 5)	1.7	ΔZ_{30} (1, 3)	3.8	ΔZ_{50} (3, 3)	3.1
4	Z_{100} (3, 3)	1.5	ΔZ_{30} (1, 5)	1.6	H_{100-30} (5, 3)	1.9
5	η_{30} (3, 3)	6.1	Z_{50} (3, 3)	1.7	ΔZ_{30} (1, 5)	1.6
6	Z_{30} (5, 3)	2.5	Z_{100} (5, 1)	3.4	Z_{500} (3, 3)	1.5
7	Z_{500} (5, 3)	2.3	Z_{30} (5, 3)	0.9	Z_{100} (5, 1)	2.7
8	ΔZ_{50} (1, 3)	1.1	Z_{500} (1, 3)	0.7	$\Delta\eta_{50}$ (3, 3)	0.6
9	$\Delta H_{200-100}$ (3, 3)	0.6	Z_{500} (5, 3)	1.0	Z_{500} (1, 5)	0.6
10	Z_{500} (5, 1)	0.5	ΔZ_{30} (3, 3)	0.5	η_{500} (3, 3)	0.5
11	Z_{500} (5, 5)	0.4	Z_{50} (1, 3)	0.5	$H_{200-100}$ (1, 1)	0.6
12	ΔZ_{200} (1, 3)	0.4	ΔZ_{50} (1, 5)	0.5	ΔZ_{100} (3, 3)	0.5
13	$H_{500-300}$ (3, 3)	0.5	ΔZ_{500} (1, 3)	0.2	ΔZ_{50} (1, 3)	0.5
14	Z_{200} (1, 5)	0.4	Z_{300} (3, 3)	0.4	$H_{200-100}$ (1, 3)	0.7
15	Z_{300} (5, 1)	0.3	—	—	$H_{500-300}$ (5, 1)	0.3
16	Z_{200} (5, 1)	0.5	—	—	Z_{200} (3, 3)	0.4
17	Z_{100} (5, 3)	0.5	—	—	$H_{500-300}$ (1, 3)	0.4
18	—	—	—	—	Z_{300} (3, 3)	0.4
19	—	—	—	—	Z_{100} (5, 3)	0.4
20	—	—	—	—	Z_{50} (5, 3)	0.5
Total	—	44.8	—	41.9	—	47.7

TABLE VII

PREDICTORS SELECTED BY SCREENING REGRESSION FOR EXP. 4

(flow oriented, with prognoses, unstratified)

(a) 24-hr forecast interval

Order of selection	$\Delta\hat{Z}_{100}$		$\Delta\hat{Z}_{50}$		$\Delta\hat{Z}_{30}$	
	predictor	% reduction	predictor	% reduction	predictor	% reduction
1	$\Delta Z_{200}(24)$ (3, 3)	56.5	ΔZ_{50} (1, 3)	24.7	ΔZ_{50} (3, 3)	21.7
2	ΔZ_{50} (1, 3)	7.5	$\Delta Z_{200}(24)$ (3, 3)	6.5	ΔZ_{30} (1, 3)	9.2
3	$\Delta Z_{200}(24)$ (5, 3)	3.5	ΔZ_{30} (3, 3)	5.3	H_{100-30} (3, 3)	2.7
4	$\zeta T_{200-100}$ (3, 3)	2.2	H_{100-30} (3, 3)	3.6	$H_{200-100}$ (3, 3)	2.6
5	H_{100-30} (1, 5)	0.8	$\Delta Z_{200}(24)$ (5, 3)	2.6	Z_{30} (5, 1)	1.3
6	ΔZ_{50} (3, 3)	0.8	ΔZ_{30} (1, 3)	1.8	$\Delta\eta_{50}$ (3, 3)	1.2
7	ΔZ_{100} (1, 3)	0.6	$\Delta\eta_{50}$ (3, 3)	1.1	$\Delta\eta_{30}$ (3, 3)	0.9
8	ΔH_{100-30} (3, 3)	0.5	$\Delta Z_{200}(24)$ (5, 5)	0.9	Z_{200} (1, 5)	1.0
9	$H_{200-100}$ (3, 3)	0.5	$\Delta H_{200-100}$ (1, 3)	0.7	$\Delta Z_{200}(24)$ (3, 3)	0.8
10	H_{100-30} (3, 3)	1.0	—	—	$H_{200-100}$ (1, 3)	0.9
11	$H_{200-100}$ (1, 3)	0.7	—	—	η_{300} (3, 3)	0.7
12	H_{100-30} (1, 3)	0.9	—	—	Z_{500} (3, 3)	1.0
13	Z_{500} (3, 3)	0.4	—	—	$H_{200-100}$ (5, 5)	0.6
14	Z_{300} (5, 3)	0.8	—	—	ΔZ_{50} (5, 5)	0.8
15	$\Delta Z_{500}(24)$ (3, 3)	0.4	—	—	—	—
16	Z_{30} (5, 3)	0.4	—	—	—	—
17	$\Delta Z_{200}(24)$ (1, 1)	0.3	—	—	—	—
Total	—	77.8	—	47.2	—	45.4

TABLE VII (cont'd)

(b) 48-hr forecast interval

Order of selection	$\Delta\hat{Z}_{100}$		$\Delta\hat{Z}_{50}$		$\Delta\hat{Z}_{30}$	
	predictor	% reduction	predictor	% reduction	predictor	% reduction
1	$\Delta Z_{200}(48)$ (3, 3)	64.8	ΔZ_{50} (1, 3)	21.3	ΔZ_{30} (1, 3)	22.2
2	$H_{200-100}$ (3, 3)	6.7	$\Delta Z_{200}(48)$ (3, 3)	11.0	H_{100-30} (3, 3)	8.3
3	ΔZ_{50} (1, 3)	4.0	H_{100-30} (3, 3)	7.0	$\Delta Z_{200}(48)$ (3, 3)	4.7
4	$\Delta Z_{200}(48)$ (5, 3)	2.4	ΔH_{100-30} (1, 3)	3.8	ΔZ_{50} (3, 3)	3.9
5	ΔZ_{50} (1, 5)	0.8	$\Delta Z_{200}(48)$ (5, 5)	3.0	Z_{500} (1, 5)	2.0
6	H_{100-30} (5, 3)	0.8	H_{100-30} (5, 3)	1.7	Z_{30} (5, 1)	2.3
7	Z_{500} (3, 3)	0.9	ΔZ_{30} (1, 5)	1.8	ΔH_{100-30} (1, 5)	1.4
8	Z_{50} (1, 3)	0.7	ΔZ_{30} (3, 3)	1.2	Z_{500} (5, 5)	1.2
9	$\Delta Z_{500}(48)$ (3, 3)	0.6	$\Delta Z_{200}(48)$ (5, 1)	1.1	$\Delta Z_{200}(48)$ (5, 3)	0.9
10	Z_{50} (3, 3)	0.5	$\Delta\eta_{50}$ (3, 3)	0.5	ΔZ_{200} (3, 3)	0.8
11	$\Delta Z_{200}(48)$ (5, 5)	0.6	$\Delta Z_{200}(48)$ (1, 1)	0.4	$\Delta\eta_{50}$ (3, 3)	0.7
12	$\Delta Z_{200}(48)$ (5, 1)	0.3	$\Delta H_{200-100}$ (1, 3)	0.5	ΔZ_{200} (1, 3)	0.5
13	Z_{500} (5, 1)	0.4	V (3, 3)	0.4	ΔZ_{50} (1, 3)	0.5
14	$H_{200-100}$ (1, 3)	0.5	Z_{500} (1, 5)	0.3	$\Delta Z_{500}(48)$ (1, 1)	0.5
15	—	—	$H_{500-300}$ (1, 5)	0.6	ΔZ_{50} (1, 5)	0.3
16	—	—	Z_{200} (5, 1)	0.3	Z_{500} (3, 3)	0.4
17	—	—	Z_{50} (3, 3)	1.4	η_{200} (3, 3)	0.5
18	—	—	—	—	$H_{200-100}$ (1, 3)	0.5
19	—	—	—	—	$H_{500-300}$ (1, 1)	0.5
20	—	—	—	—	H_{100-30} (1, 1)	0.5
Total	—	84.0	—	56.3	—	52.6

9. Experiments 5 and 6

These two experiments incorporated the idea of geographical stratification in a simple, straightforward manner. The predictand area (Fig. 1) was merely subdivided into four regions (NW, NE, SE, SW), each consisting of 12 predictand points and a sample size of 780 cases, or one-fourth the total dependent sample. The prognostic predictors were excluded in Exp. 5 and included in Exp. 6 with the grid oriented north-south for both experiments. The predictors in the order of their selection are not shown, but the total PR's are shown in Table VIII, which summarizes the results of all the experiments on dependent data. Generally speaking, the first predictor selected was similar to those in the unstratified experiments.

10. Independent Data Tests

Equations developed from the six types of experiments described above were applied to a set of independent data consisting of 768 cases taken from 16 map times. In addition, the technique of persistence was applied to the sample for control purposes (the state-of-the-art justifies this kind of comparison especially at 50 and 30 mb). Root-mean-square (rms) errors (in feet) are shown in Table IX. For Exps. 5 and 6, the results for the individual four stratified areas have been pooled for comparative purposes. Many of the comments on dependent data comparisons apply as well to the independent data.

The introduction of prognostic predictors (Exp. 1 vs 2, Exp. 3 vs 4, Exp. 5 vs 6) results in significant improvement, particularly at 100 mb. This is due to the rather high correlation between height changes at 200 mb (the highest predictor level) and 100 mb (the lowest predictand level). The comparisons between north-south and flow orientation (Exp. 1 vs 3, Exp. 2 vs 4) seem to indicate that there is little to be gained by orienting the grid with respect to the flow. The crude stratification technique employed (Exp. 1 vs 5, Exp. 2 vs 6) appears to have been successful, especially for the 48-hr forecast interval. The technique of persistence yielded the largest rms errors for all levels and forecast intervals.

The application of Exps. 1 and 2, 48-hr prediction equations, and persistence to one of the independent data situations (1200 GMT, 30 December 1963) is shown in Figs. 3–6. The superimposed error fields (in tens of feet) are represented by dashed lines. Figure 3 shows the initial 100-mb chart of 1200 GMT, 30 December 1963. The major feature of this map is the large trough extending from east of Hudson Bay south-

TABLE VIII
RESULTS ON DEPENDENT DATA

Exp.	Forecast interval (hr)	No. of predictors			Standard deviation (ft)			Residual std. dev. (ft)			% reduction		
		$\Delta\hat{Z}_{100}$	$\Delta\hat{Z}_{50}$	$\Delta\hat{Z}_{30}$	$\Delta\hat{Z}_{100}$	$\Delta\hat{Z}_{50}$	$\Delta\hat{Z}_{30}$	$\Delta\hat{Z}_{100}$	$\Delta\hat{Z}_{50}$	$\Delta\hat{Z}_{30}$	$\Delta\hat{Z}_{100}$	$\Delta\hat{Z}_{50}$	$\Delta\hat{Z}_{30}$
1	24	13	19	13	256	225	255	192	167	191	43.5	45.2	44.4
	48	20	10	15	412	393	432	300	295	303	46.8	43.6	50.9
2	24	19	20	20	256	225	255	119	149	181	78.4	56.1	50.0
	48	16	19	20	412	393	432	158	234	279	85.3	64.6	58.3
3	24	17	8	13	256	225	255	180	174	193	50.7	40.4	43.4
	48	17	14	20	412	393	432	306	301	313	44.8	41.9	47.7
4	24	17	9	14	256	225	255	121	164	189	77.8	47.2	45.4
	48	14	17	20	412	393	432	165	261	331	84.0	56.3	52.6
5 (NW)	24	20	20	9	272	261	300	175	164	191	58.5	60.6	59.5
	48	20	20	20	462	465	536	276	288	303	64.3	61.6	68.2
(NE)	24	14	20	20	289	313	365	205	200	212	49.6	59.1	66.4
	48	20	14	14	455	551	603	295	337	361	58.1	62.7	64.1
(SE)	24	7	10	8	232	147	156	172	114	129	44.8	39.6	32.2
	48	20	7	20	341	235	242	225	178	167	56.5	42.7	52.4
(SW)	24	20	18	6	223	122	115	124	77	91	69.2	59.7	37.6
	48	12	20	15	372	207	194	206	123	123	69.4	64.5	60.2
6 (NW)	24	15	20	20	272	261	300	113	144	169	82.8	69.4	68.3
	48	13	20	9	462	465	536	152	231	305	89.2	75.4	67.6
(NE)	24	14	20	12	289	313	365	140	179	237	76.7	67.3	57.9
	48	20	20	20	455	551	603	161	256	274	87.5	78.3	79.3
(SE)	24	20	8	13	232	147	156	91	100	115	84.5	53.2	45.5
	48	14	12	20	341	235	242	98	125	146	91.8	71.9	63.8
(SW)	24	20	20	16	223	122	115	73	65	77	89.2	71.7	54.9
	48	20	20	10	372	207	194	85	91	125	94.8	80.6	58.4

TABLE IX

RMS ERRORS (ft) ON INDEPENDENT DATA (768 cases)

Forecast interval (hr)	Predictand	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Persistence
24	$\Delta\hat{Z}_{100}$	218	125	208	127	206	119	280
	$\Delta\hat{Z}_{50}$	202	173	207	185	193	162	262
	$\Delta\hat{Z}_{30}$	220	201	223	212	205	194	286
48	$\Delta\hat{Z}_{100}$	303	163	310	170	283	142	411
	$\Delta\hat{Z}_{50}$	291	232	303	263	251	211	410
	$\Delta\hat{Z}_{30}$	307	299	326	305	275	253	455

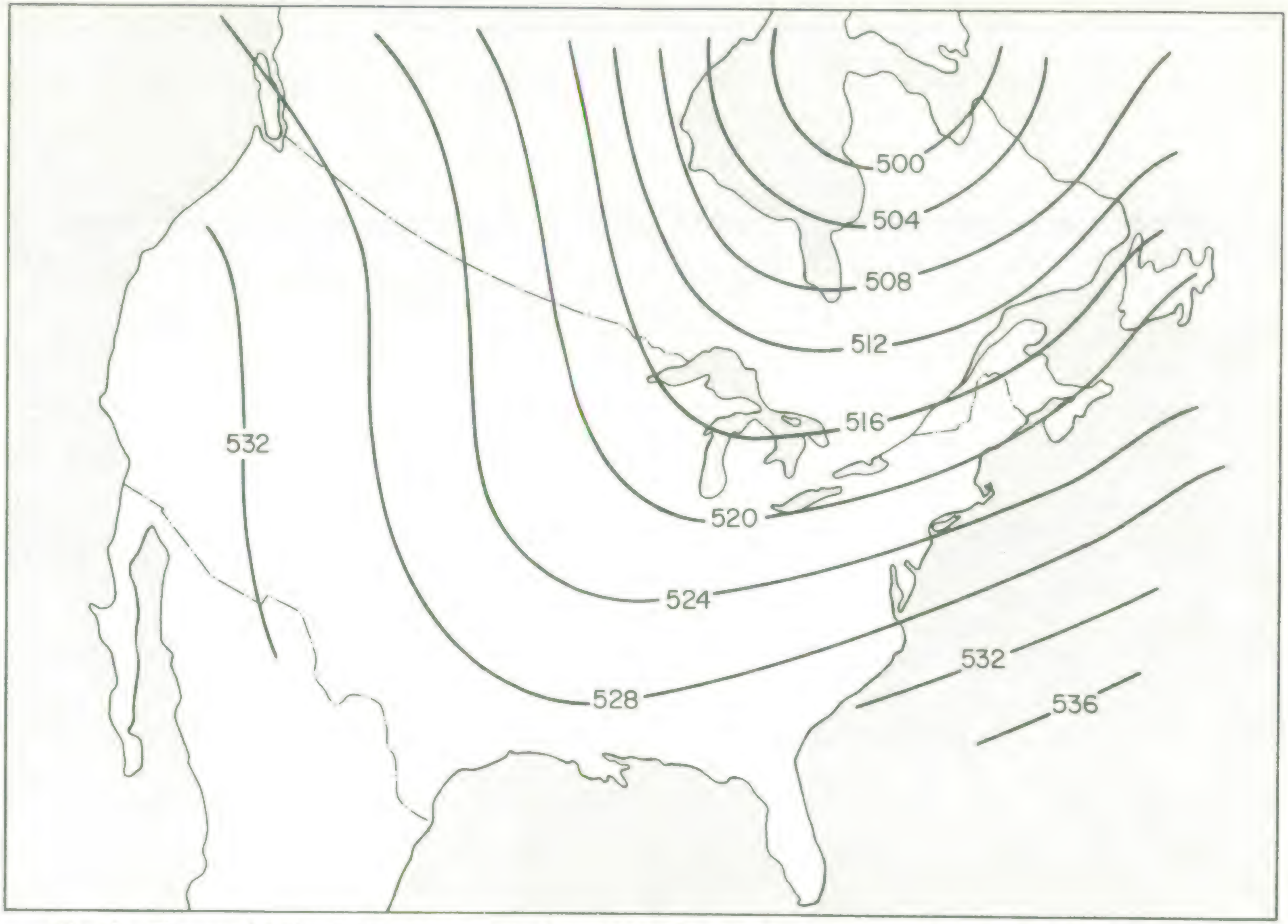

Fig. 3. Observed 100-mb height analysis for 1200 GMT, 30 December 1963. Heights are in hundreds of feet.

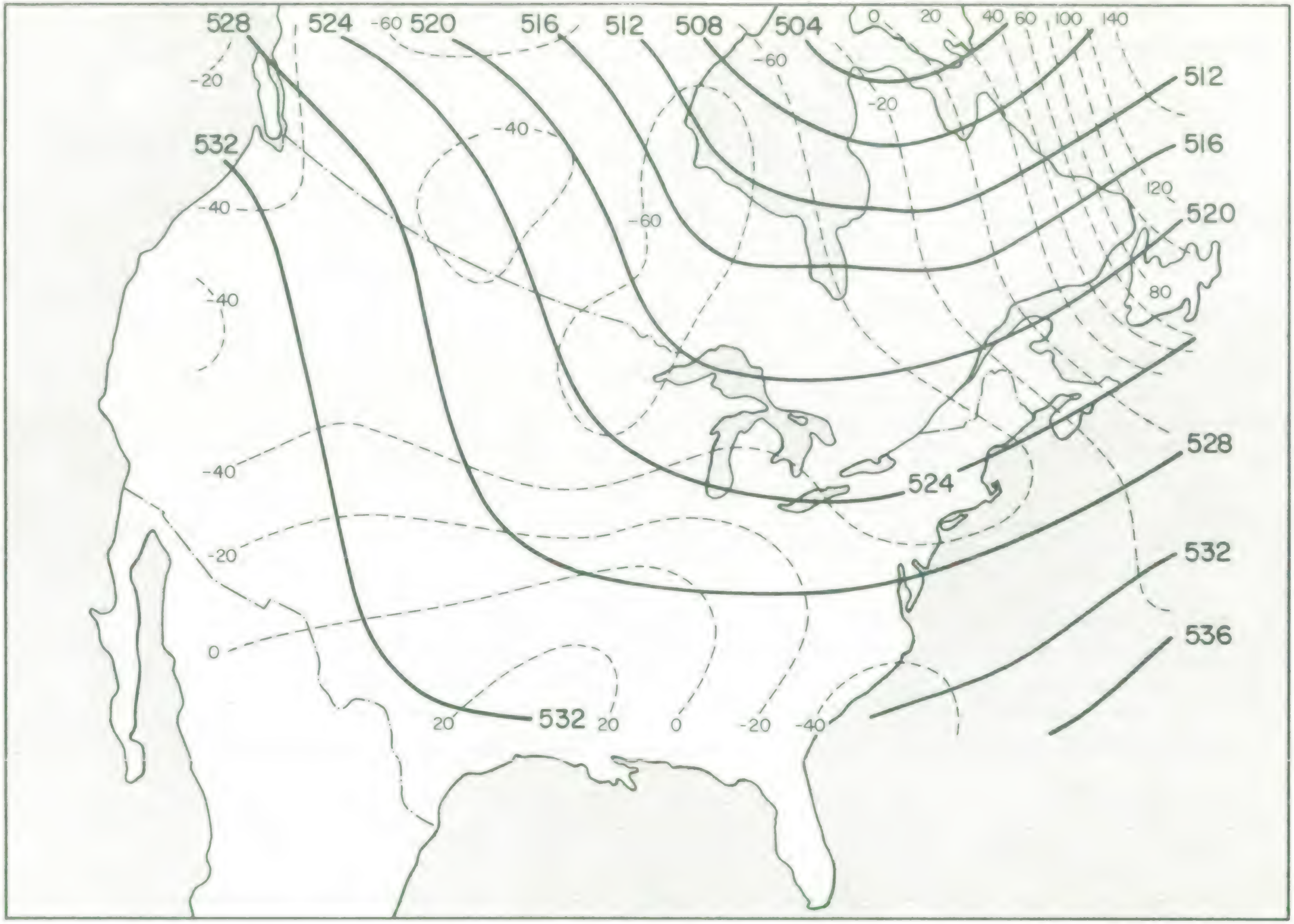

Fig. 4. Experiment 1—48-hr 100-mb height prognosis; valid 1200 GMT, 1 January 1964. Heights are in hundreds of feet. Error field (in tens of feet) is superimposed in dashed lines.

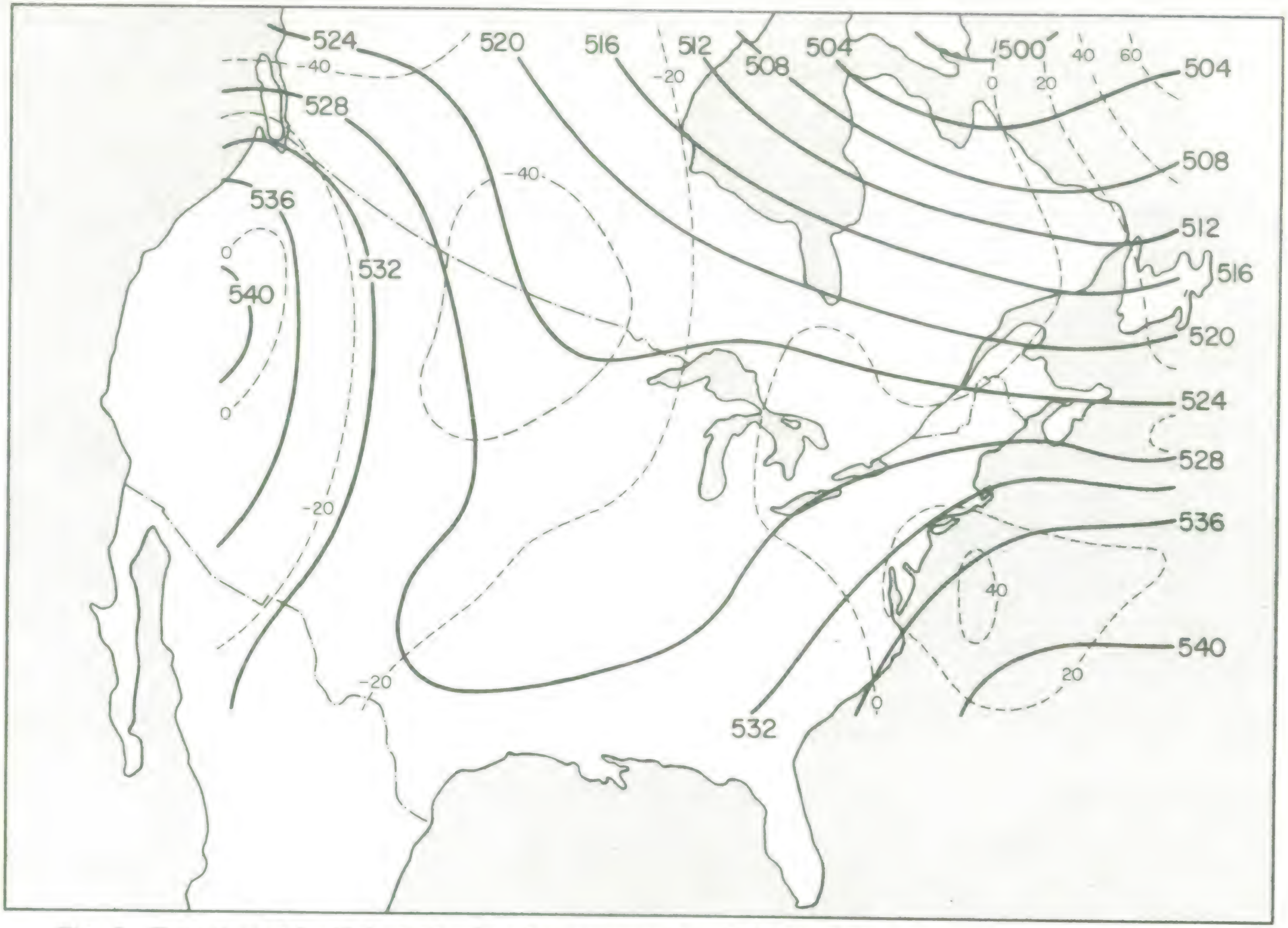

Fig. 5. Experiment 2—48-hr 100-mb height prognosis; valid 1200 GMT, 1 January 1964. Heights are in hundreds of feet. Error field (in tens of feet) is superimposed in dashed lines.

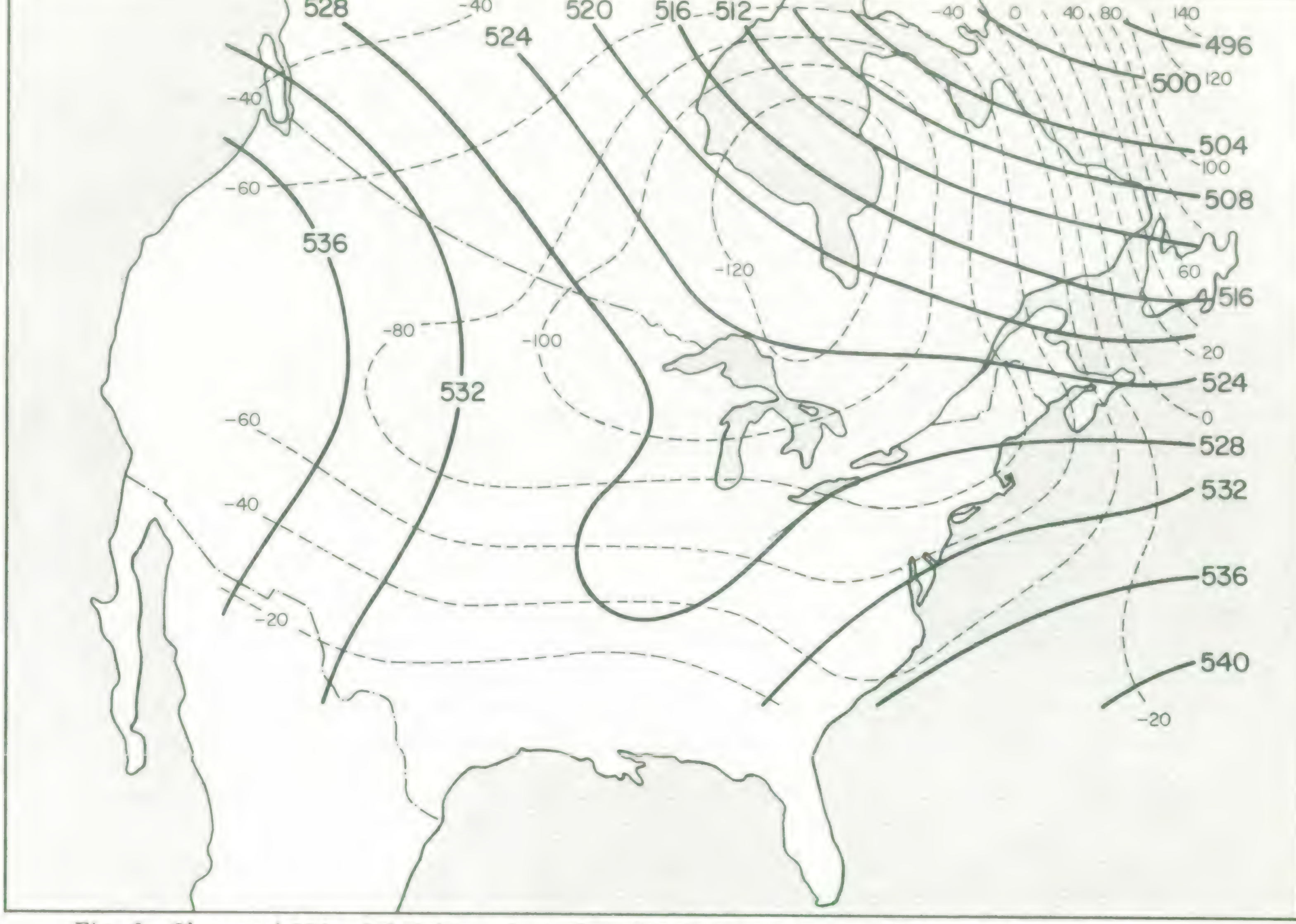

Fig. 6. Observed 100-mb height analysis for 1200 GMT, 1 January 1964. Heights are in hundreds of feet. Dashed lines are the error field (tens of feet) for 48-hr persistence.

westward to Texas. During the ensuing 48 hr, the northern portion of this trough moved rapidly eastward leaving a rather weak trough over the Mississippi Valley area (see Fig. 6). The accompanying 48-hr height changes are equal, but of opposite sign, to the error field of the persistence technique which is represented in Fig. 6 by the dashed lines. Note the 1400-ft height falls in the upper right portion of the map, while most of the remainder of the map is characterized by height rises, with a height rise center in excess of 1200 ft in the vicinity of James Bay. The Exp. 1 prediction equation results (north-south orientation, no prognoses, unstratified) are shown in Fig. 4. There has been a broadening in the trough predicted rather than an eastward displacement. The main problem here is the 1400-ft errors near the upper right corner of the map. Some of the height rises over the continent have been indicated to some extent with the largest errors being around 600 ft.

The results using the Exp. 2 equation (north-south orientation, with prognoses) show an appreciable improvement (Fig. 5). The main features have been explained fairly well: the eastward displacement of the northern portion of the trough, the lingering trough over the central U.S., and the building ridge over the western U.S. The 1200-ft rises over James Bay have been almost entirely predicted in this case. The overall rms error for this example is 705 ft for persistence, 469 ft for Exp. 1, and 249 ft for Exp 2.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

The successful results of this limited feasibility test on stratospheric-circulation prediction clearly indicate that further research of greater proportion in this area is warranted. While the application of real prognoses may not yield the spectacular results that perfect prognoses do, it should be noted that even the simplest base technique devised (north-south orientation, no prognoses, and no stratification) yielded results superior to persistence for all three levels and both forecast intervals. Although the use of a flow orientation failed to yield much improvement, the adoption of a simple stratification scheme gave encouraging results.

A logical follow-on research plan would include:

(a) the extension of technique development to the entire Northern Hemisphere and to other seasons,

(b) derivation of additional predictors; for example, the concept of vorticity conservation could be employed as is done in graphical prognostic techniques to derive possible predictors.

(c) experimentation with the use of absolute vorticity as the predictand and recovering the height field by relaxation methods.

(d) experimentation with the use of the height gradient as a predictand rather than the value of the height at a point.

(e) analysis of results incorporating operational prognoses rather than perfect prognoses.

If the necessary effort could be applied, implementable results could be made available in nine to twelve months.

APPENDIX

PREDICTION EQUATIONS

The prediction equations derived from the regression analysis have the form

$$\hat{Y} = A_0 + A_1X_1 + A_2X_2 + \ldots + A_nX_n, \tag{A-1}$$

where $\hat{Y}$ is the predictand, the A's are constant coefficients derived (by the method of least squares) from the developmental sample, and the X's are the predictors selected by the screening procedure.

Each set of prediction equations consists of six equations: the three predictands of 100-, 50-, and 30-mb height change for 24 and 48 hr. Equations from experiments 5 and 6 have not been included.

The pair of numbers that is associated with a given predictor in the equations refers to the grid location in the (K, L)-grid system of Figure 2. The symbols and units used are defined in Tables I and II. Note that while the error statistics in the report are in whole feet, the predictands in these equations are in tens of feet.

Exp. 1 (north-south orientation, no prognoses)

$$\Delta\hat{Z}_{100}(24) = -28.024 + 0.4564\,\Delta Z_{100}(1,3) + 0.4698\,\Delta Z_{500}(3,3) + 3{,}214{,}000\,\Delta\eta_{500}(3,3)$$
$$-0.0809\,H_{200-100}(5,5) - 1{,}035{,}400\,\zeta T_{100-30}(3,3) + 0.1287\,\Delta Z_{30}(1,5)$$
$$-0.1315\,H_{200-100}(1,1) - 0.2862\,Z_{100}(3,3) + 0.1322\,Z_{100}(1,3)$$
$$+0.0539\,Z_{30}(5,1) + 0.2391\,\Delta Z_{50}(3,3) + 0.0898\,Z_{500}(5,3) + 0.0827\,Z_{50}(3,3)$$

$$\Delta\hat{Z}_{50}(24) = -490.62 + 0.3360\,\Delta Z_{50}(1,3) + 0.6364\,\Delta Z_{100}(3,3) + 0.2985\,\Delta H_{100-30}(3,3)$$
$$+0.0790\,\Delta Z_{30}(1,5) - 0.0298\,H_{200-100}(5,5) + 2{,}834{,}400\,\Delta\eta_{50}(3,3)$$
$$-0.0504\,\Delta Z_{500}(1,5) + 0.0992\,Z_{500}(1,1) - 0.1901\,Z_{50}(3,3) + 0.1265\,Z_{30}(5,1)$$
$$+0.0435\,Z_{30}(1,5) - 0.0833\,Z_{500}(1,5) + 0.1115\,H_{500-300}(1,5)$$
$$+4{,}132{,}100\,\Delta\eta_{30}(3,3) - 1{,}818{,}900\,\Delta\zeta T_{100-30}(3,3) - 0.1866\,\Delta Z_{50}(1,1)$$
$$+0.0982\,\Delta Z_{30}(1,3) - 0.0457\,H_{100-30}(5,3) + 0.0552\,Z_{30}(1,3)$$

$$\Delta\hat{Z}_{30}(24) = -121.43 + 0.6026\,\Delta Z_{50}(3,3) + 0.2142\,\Delta Z_{30}(1,3) - 0.2583\,H_{100-30}(3,3)$$
$$+0.1972\,H_{200-100}(3,3) + 4{,}157{,}600\,\Delta\eta_{50}(3,3) + 2{,}810{,}700\,\Delta\eta_{30}(3,3)$$
$$+0.1343\,H_{100-30}(1,5) + 0.2154\,\Delta Z_{50}(1,3) - 0.0510\,Z_{50}(5,5)$$
$$+0.3367\,Z_{30}(5,1) - 0.2471\,Z_{50}(5,1) - 450{,}920\,\eta_{50}(3,3) - 0.0828\,Z_{100}(3,3)$$

$$\Delta\hat{Z}_{100}(48) = 487.06 + 0.4906\,\Delta Z_{100}(1,3) + 0.4784\,\Delta Z_{50}(1,5) - 0.0302\,H_{200-100}(1,5)$$
$$-1.1130\,Z_{100}(3,3) - 1{,}385{,}500\,\eta_{30}(3,3) + 0.4716\,H_{500-300}(1,5)$$
$$+0.0217\,Z_{50}(1,1) + 0.1427\,H_{100-30}(5,1) + 0.2013\,Z_{500}(5,3)$$
$$+0.2447\,\Delta Z_{200}(3,3) + 0.2271\,Z_{500}(1,1) - 0.3735\,\Delta Z_{50}(1,1)$$
$$-0.2112\,\Delta H_{200-100}(1,3) - 0.4239\,Z_{300}(1,5) + 0.1827\,Z_{30}(1,3)$$
$$-0.0612\,H_{100-30}(5,5) + 0.1194\,Z_{300}(3,3) + 0.4177\,Z_{50}(3,3)$$
$$+0.2897\,Z_{200}(1,5) - 0.2206\,H_{100-30}(3,3)$$

$$Z_{50}(48) = -799.91 + 0.5666\,\Delta Z_{50}(1,3) + 0.3956\,\Delta Z_{30}(1,5) - 0.0543\,H_{100-30}(1,3)$$
$$-0.0777\,Z_{50}(5,5) + 0.1559\,Z_{200}(1,1) - 0.3213\,Z_{50}(3,3) + 0.2550\,Z_{30}(5,1)$$
$$+0.3634\,Z_{50}(1,5) - 0.4277\,Z_{500}(1,5) - 0.4645\,H_{200-100}(1,5)$$

$$Z_{30}(48) = -183.59 + 0.3662\,\Delta Z_{30}(1,3) - 0.5136\,H_{100-30}(3,3) + 0.2948\,\Delta Z_{30}(1,5)$$
$$+0.5383\,\Delta Z_{50}(3,3) - 0.0774\,Z_{50}(5,5) + 0.0276\,Z_{100}(1,1) - 0.3107\,Z_{200}(3,3)$$
$$+0.7395\,Z_{30}(5,1) + 0.1545\,H_{100-30}(1,5) - 0.5978\,Z_{50}(5,1)$$
$$-1{,}191{,}100\,\eta_{200}(3,3) + 0.5759\,H_{500-300}(1,5) - 0.2361\,Z_{300}(1,5)$$
$$+0.1536\,Z_{50}(1,3) + 4{,}529{,}800\,\Delta\eta_{50}(3,3)$$

Exp. 2 (north-south orientation, with prognoses)

$$\Delta\hat{Z}_{100}(24) = -3.3696 + 0.5266\,\Delta Z_{200}(24)(3,3) + 0.2097\,\Delta Z_{50}(1,3) - 0.3916\,H_{200-100}(3,3)$$
$$+0.1808\,H_{200-100}(1,3) + 0.2000\,H_{100-30}(3,3) - 0.1270\,H_{100-30}(1,3)$$
$$+0.2589\,\Delta Z_{50}(3,3) + 0.0572\,\Delta Z_{200}(24)(5,3) - 0.0175\,H_{100-30}(5,5)$$
$$+0.0541\,\Delta H_{100-30}(1,5) + 2{,}060{,}500\,\Delta\eta_{50}(3,3) + 0.0462\,\Delta Z_{200}(24)(1,1)$$
$$+0.0850\,\Delta Z_{500}(24)(5,1) + 0.1003\,\Delta Z_{500}(1,1) - 0.0500\,\Delta Z_{500}(3,3)$$
$$+0.1096\,H_{500-300}(1,5) - 0.0696\,Z_{500}(1,5) - 0.0741\,Z_{500}(3,3)$$
$$+0.0452\,Z_{50}(1,5)$$

$$\Delta\hat{Z}_{50}(24) = -479.07 + 0.2889\,\Delta Z_{50}(1,3) + 0.2413\,\Delta Z_{200}(24)(3,3) + 0.2926\,\Delta Z_{30}(3,3)$$
$$-0.0141\,H_{100-30}(3,3) + 0.0602\,\Delta Z_{200}(24)(5,3) + 0.0519\,\Delta H_{100-30}(1,5)$$
$$+2{,}598{,}300\,\Delta\eta_{50}(3,3) + 0.1470\,\Delta Z_{30}(1,3) + 0.0432\,\Delta Z_{200}(24)(5,5)$$
$$+0.0954\,\Delta Z_{500}(24)(5,1) + 0.1354\,H_{200-100}(1,3) + 0.1198\,Z_{500}(1,1)$$
$$-0.1916\,Z_{50}(3,3) + 0.1705\,H_{500-300}(3,3) + 0.1039\,\Delta Z_{500}(24)(1,1)$$
$$+0.1197\,Z_{50}(1,5) + 0.0985\,Z_{30}(5,1) - 0.1263\,Z_{500}(1,5)$$
$$+2{,}036{,}900\,\Delta\eta_{30}(3,3) - 0.1131\,H_{200-100}(1,5)$$

$$\Delta\hat{Z}_{30}(24) = -265.73 + 0.4563\,\Delta Z_{50}(3,3) + 0.3279\,\Delta Z_{30}(1,3) - 0.2443\,H_{100-30}(3,3)$$
$$+0.0294\,H_{200-100}(3,3) + 3{,}001{,}900\,\Delta\eta_{50}(3,3) + 0.1338\,\Delta Z_{200}(24)(3,3)$$
$$+0.1126\,H_{100-30}(1,5) + 2{,}780{,}400\,\Delta\eta_{30}(3,3) - 0.0440\,Z_{50}(5,5)$$
$$+0.2567\,Z_{30}(5,1) + 0.0983\,\Delta Z_{500}(24)(5,1) - 0.1447\,Z_{500}(3,3)$$
$$-315{,}250\,\eta_{300}(3,3) - 0.1786\,Z_{50}(5,1) + 0.1060\,H_{200-100}(1,3)$$
$$+0.1286\,\Delta Z_{500}(24)(1,1) + 0.0958\,Z_{500}(1,1) + 0.0737\,\Delta Z_{500}(24)(5,3)$$
$$+0.1046\,\Delta Z_{100}(5,5) + 0.0940\,\Delta Z_{500}(5,3)$$

$$\Delta\hat{Z}_{100}(48) = -505.36 + 0.7019\,\Delta Z_{200}(48)(3,3) - 0.6575\,H_{200\text{-}100}(3,3)$$
$$+0.2482\,\Delta Z_{50}(1,5) + 0.0771\,\Delta Z_{200}(48)(5,3) + 0.1680\,\Delta Z_{50}(1,3)$$
$$+0.3106\,H_{200\text{-}100}(1,3) + 0.0848\,H_{100\text{-}30}(3,3) - 0.2473\,Z_{500}(3,3)$$
$$+0.1178\,Z_{300}(1,3) - 0.1617\,\Delta Z_{500}(48)(3,3) + 0.0850\,Z_{30}(5,1)$$
$$+0.0876\,H_{200\text{-}100}(1,5) + 0.2307\,H_{500\text{-}300}(1,5) - 0.0938\,Z_{500}(1,5)$$
$$+0.0997\,\Delta Z_{500}(48)(5,1) + 0.1345\,\Delta Z_{500}(24)(1,1)$$

$$\Delta\hat{Z}_{50}(48) = -227.75 + 0.2911\,\Delta Z_{50}(1,3) + 0.2702\,\Delta Z_{200}(48)(3,3) + 0.0086\,H_{100\text{-}30}(3,3)$$
$$+0.2956\,\Delta Z_{30}(1,5) + 0.1412\,\Delta Z_{200}(48)(5,3) + 0.3114\,\Delta Z_{30}(1,3)$$
$$+0.2067\,\Delta Z_{500}(48)(5,1) + 0.3145\,\Delta Z_{500}(24)(1,1) - 0.0637\,\Delta Z_{200}(1,3)$$
$$-0.4746\,Z_{500}(1,5) + 0.2482\,Z_{300}(1,5) + 0.2393\,Z_{500}(1,1) - 0.4028\,Z_{50}(3,3)$$
$$+0.0962\,Z_{50}(5,1) + 0.1575\,Z_{50}(1,5) + 0.2729\,H_{500\text{-}300}(3,3)$$
$$-0.1199\,Z_{100}(5,5) + 0.1717\,Z_{100}(5,3) + 0.1837\,H_{200\text{-}100}(1,3)$$

$$\Delta\hat{Z}_{30}(48) = -699.10 + 0.4809\,\Delta Z_{30}(1,3) - 0.3604\,H_{100\text{-}30}(3,3) + 0.1889\,\Delta Z_{200}(48)(3,3)$$
$$+0.1936\,\Delta H_{100\text{-}30}(1,5) + 0.2750\,\Delta Z_{50}(3,3) + 0.2185\,\Delta Z_{500}(48)(5,1)$$
$$-0.1520\,Z_{500}(1,5) + 0.3754\,H_{500\text{-}300}(1,5) - 0.0793\,Z_{500}(5,5)$$
$$+0.5851\,Z_{30}(5,1) + 0.1228\,\Delta Z_{500}(48)(5,3) + 0.1265\,H_{200\text{-}100}(1,3)$$
$$+0.2281\,\Delta Z_{500}(24)(1,1) - 0.2195\,H_{100\text{-}30}(1,1) - 0.1548\,Z_{50}(5,3)$$
$$+0.1577\,H_{100\text{-}30}(1,5) - 0.1470\,Z_{500}(3,3) + 0.2462\,\Delta Z_{50}(1,5)$$
$$+0.2491\,\Delta Z_{50}(5,3) - 0.2573\,Z_{50}(5,1)$$

Exp. 3 (flow orientation, no prognoses)

$$\Delta\hat{Z}_{100}(24) = -9.3100 + 0.2207\,\Delta Z_{100}(1,3) + 0.3918\,\Delta Z_{500}(3,3) - 0.0540\,Z_{30}(1,3)$$
$$+0.1927\,\Delta Z_{30}(3,3) + 0.0943\,Z_{30}(5,3) + 0.1243\,Z_{50}(3,3) + 0.0502\,Z_{500}(5,5)$$
$$+2{,}785{,}800\,\Delta\eta_{500}(3,3) + 0.2819\,\Delta Z_{50}(1,3) - 0.3645\,Z_{100}(3,3)$$
$$+0.0965\,Z_{300}(5,3) + 0.0764\,Z_{500}(5,1) + 0.2451\,H_{500-300}(3,3)$$
$$+1{,}755{,}100\,\xi T_{500-300}(3,3) + 0.1703\,\Delta Z_{200}(1,3) - 0.0751\,Z_{500}(1,3)$$
$$+0.1004\,H_{500-300}(1,5)$$

$$\Delta\hat{Z}_{50}(24) = 73.1790 + 0.3935\,\Delta Z_{50}(1,3) + 0.4716\,\Delta Z_{100}(3,3) + 0.2734\,\Delta Z_{30}(1,3)$$
$$+0.2334\,\Delta H_{100-30}(3,3) - 0.0138\,Z_{30}(1,3) + 0.0887\,Z_{100}(5,1)$$
$$+3{,}157{,}300\,\Delta\eta_{50}(3,3) - 0.0665\,Z_{50}(3,3)$$

$$\Delta\hat{Z}_{30}(24) = -282.83 + 0.5481\,\Delta Z_{50}(3,3) + 0.3406\,\Delta Z_{30}(1,3) - 0.2432\,H_{100-30}(3,3)$$
$$+0.1504\,H_{200-100}(3,3) + 0.2431\,Z_{30}(5,1) + 3{,}174{,}300\,\Delta\eta_{50}(3,3)$$
$$+2{,}494{,}700\,\Delta\eta_{30}(3,3) - 0.0085\,Z_{200}(1,5) + 0.1460\,\Delta Z_{30}(5,3)$$
$$+0.2317\,\Delta Z_{50}(1,3) - 0.1609\,Z_{50}(5,1) + 0.0606\,H_{100-30}(1,5)$$
$$-0.0499\,Z_{100}(3,3)$$

$$\Delta\hat{Z}_{100}(48) = 284.40 + 0.2774\,\Delta Z_{100}(1,3) + 0.0352\,H_{200-100}(1,5) + 0.3235\,\Delta Z_{50}(1,5)$$
$$-0.4972\,Z_{100}(3,3) - 285{,}230\,\eta_{30}(3,3) + 0.2211\,Z_{30}(5,3) + 0.2131\,Z_{500}(5,3)$$
$$+0.4454\,\Delta Z_{50}(1,3) - 0.1491\,\Delta H_{200-100}(3,3) + 0.5644\,Z_{500}(5,1)$$
$$+0.0754\,Z_{500}(5,5) + 0.2025\,\Delta Z_{200}(1,3) + 0.2219\,H_{500-300}(3,3)$$
$$+0.0663\,Z_{200}(1,5) - 0.6595\,Z_{300}(5,1) + 0.3910\,Z_{200}(5,1) - 0.1908\,Z_{100}(5,3)$$

$$\Delta\hat{Z}_{50}(48) = -246.20 + 0.3621\,\Delta Z_{50}(1,3) - 0.1228\,H_{100\text{-}30}(1,3) + 0.4462\,\Delta Z_{30}(1,3)$$
$$+0.1763\,\Delta Z_{30}(1,5) - 0.3984\,Z_{50}(3,3) + 0.1326\,Z_{100}(5,1)$$
$$+0.1949\,Z_{30}(5,3) - 0.2248\,Z_{500}(1,3) + 0.0777\,Z_{500}(5,3)$$
$$+0.2040\,\Delta Z_{30}(3,3) + 0.1630\,Z_{50}(1,3) + 0.2064\,\Delta Z_{50}(1,5)$$
$$+0.1946\,\Delta Z_{500}(1,3) + 0.0542\,Z_{300}(3,3)$$

$$\Delta\hat{Z}_{30}(48) = -142.22 + 0.5430\,\Delta Z_{30}(1,3) - 0.5100\,H_{100\text{-}30}(3,3) + 0.6605\,\Delta Z_{50}(3,3)$$
$$+0.3957\,H_{100\text{-}30}(5,3) + 0.2485\,\Delta Z_{30}(1,5) - 0.3572\,Z_{500}(3,3)$$
$$+0.2128\,Z_{100}(5,1) + 5{,}077{,}600\,\Delta\eta_{50}(3,3) - 0.0824\,Z_{500}(1,5)$$
$$-877{,}570\,\eta_{500}(3,3) + 0.1108\,H_{200\text{-}100}(1,1) - 0.3335\,\Delta Z_{100}(3,3)$$
$$+0.3071\,\Delta Z_{50}(1,3) + 0.2880\,H_{200\text{-}100}(1,3) - 0.3151\,H_{500\text{-}300}(5,1)$$
$$-0.5212\,Z_{200}(3,3) + 0.2267\,H_{500\text{-}300}(1,3) + 0.4773\,Z_{300}(3,3)$$
$$+0.4039\,Z_{100}(5,3) - 0.2766\,Z_{50}(5,3)$$

Exp. 4 (flow orientation, with prognoses)

$$\Delta\hat{Z}_{100}(24) = -79.455 + 0.5704\,\Delta Z_{200}(24)(3,3) + 0.2455\,\Delta Z_{50}(1,3)$$
$$+0.0747\,\Delta Z_{200}(24)(5,3) + 827{,}690\,\xi T_{200-100}(3,3) - 0.0015\,H_{100-30}(1,5)$$
$$+0.1719\,\Delta Z_{50}(3,3) + 0.1003\,\Delta Z_{100}(1,3) + 0.0877\,\Delta H_{100-30}(3,3)$$
$$-0.3520\,H_{200-100}(3,3) + 0.0837\,H_{100-30}(3,3) + 0.1836\,H_{200-100}(1,3)$$
$$-0.0696\,H_{100-30}(1,3) - 0.1542\,Z_{500}(3,3) + 0.0484\,Z_{300}(5,3)$$
$$-0.1144\,\Delta Z_{500}(24)(3,3) + 0.0546\,Z_{30}(5,3) + 0.0442\,\Delta Z_{200}(24)(1,1)$$

$$\Delta\hat{Z}_{50}(24) = 151.55 + 0.3356\,\Delta Z_{50}(1,3) + 0.2117\,\Delta Z_{200}(24)(3,3) + 0.2597\,\Delta Z_{30}(3,3)$$
$$-0.0621\,H_{100-30}(3,3) + 0.0701\,\Delta Z_{200}(24)(5,3) + 0.2619\,\Delta Z_{30}(1,3)$$
$$+3{,}229{,}900\,\Delta\eta_{50}(3,3) + 0.0555\,\Delta Z_{200}(24)(5,5) + 0.1261\,\Delta H_{200-100}(1,3)$$

$$\Delta\hat{Z}_{30}(24) = -32.697 + 0.5201\,\Delta Z_{50}(3,3) + 0.4367\,\Delta Z_{30}(1,3) - 0.2047\,H_{100-30}(3,3)$$
$$+0.0114\,H_{200-100}(3,3) + 0.0713\,Z_{30}(5,1) + 3{,}128{,}200\,\Delta\eta_{50}(3,3)$$
$$+2{,}865{,}200\,\Delta\eta_{30}(3,3) - 0.0411\,Z_{200}(1,5) + 0.1082\,\Delta Z_{200}(24)(3,3)$$
$$+0.1603\,H_{200-100}(1,3) - 445{,}110\,\eta_{300}(3,3) - 0.0978\,Z_{500}(3,3)$$
$$+0.0751\,H_{200-100}(5,5) + 0.1265\,\Delta Z_{50}(5,5)$$

$$\Delta\hat{Z}_{100}(48) = 76.952 + 0.7417\,\Delta Z_{200}(48)(3,3) - 0.6964\,H_{200-100}(3,3)$$
$$+0.3551\,\Delta Z_{50}(1,3) + 0.0248\,\Delta Z_{200}(48)(5,3) + 0.2477\,\Delta Z_{50}(1,5)$$
$$+0.0830\,H_{100-30}(5,3) - 0.3246\,Z_{500}(3,3) + 0.0213\,Z_{50}(1,3)$$
$$-0.1980\,\Delta Z_{500}(48)(3,3) + 0.1172\,Z_{50}(3,3) + 0.0616\,\Delta Z_{200}(48)(5,5)$$
$$+0.0833\,\Delta Z_{200}(48)(5,1) + 0.1082\,Z_{500}(5,1) + 0.1199\,H_{200-100}(1,3)$$

$$
\begin{aligned}
\Delta\hat{Z}_{50}(48) \quad = \quad & 334.61 + 0.5992\,\Delta Z_{50}(1,3) + 0.3150\,\Delta Z_{200}(48)(3,3) \\
& -0.1658\,H_{100\text{-}30}(3,3) + 0.3219\,\Delta H_{100\text{-}30}(1,3) + 0.0982\,\Delta Z_{200}(48)(5,5) \\
& +0.1031\,H_{100\text{-}30}(5,3) + 0.2543\,\Delta Z_{30}(1,5) + 0.2423\,\Delta Z_{30}(3,3) \\
& +0.1359\,\Delta Z_{200}(48)(5,1) + 3{,}237{,}900\,\Delta\eta_{50}(3,3) + 0.0703\,\Delta Z_{200}(48)(1,1) \\
& +0.1521\,\Delta H_{200\text{-}100}(1,3) - 0.0651\,V(3,3) - 0.1230\,Z_{500}(1,5) \\
& +0.1586\,H_{500\text{-}300}(1,5) + 0.1225\,Z_{200}(5,1) - 0.0945\,Z_{50}(3,3)
\end{aligned}
$$

$$
\begin{aligned}
\Delta\hat{Z}_{30}(48) \quad = \quad & 543.78 + 0.5533\,\Delta Z_{30}(1,3) - 0.3323\,H_{100\text{-}30}(3,3) + 0.2203\,\Delta Z_{200}(48)(3,3) \\
& +0.5221\,\Delta Z_{50}(3,3) - 0.1457\,Z_{500}(1,5) + 0.1606\,Z_{30}(5,1) \\
& +0.1849\,\Delta H_{100\text{-}30}(1,5) - 0.0691\,Z_{500}(5,5) + 0.1023\,\Delta Z_{200}(48)(5,3) \\
& -0.2079\,\Delta Z_{200}(3,3) + 3{,}834{,}700\,\Delta\eta_{50}(3,3) - 0.1483\,\Delta Z_{200}(1,3) \\
& +0.3249\,\Delta Z_{50}(1,3) + 0.0900\,\Delta Z_{500}(48)(1,1) + 0.1923\,\Delta Z_{50}(1,5) \\
& -0.0956\,Z_{500}(3,3) - 744{,}240\,\eta_{200}(3,3) + 0.1706\,H_{200\text{-}100}(1,3) \\
& -0.2627\,H_{500\text{-}300}(1,1) - 0.1172\,H_{100\text{-}30}(1,1)
\end{aligned}
$$

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13. ABSTRACT

This report describes a base technique for the 24- and 48-hr prediction of stratospheric contour height changes in winter at 100, 50, and 30 mb. On independent data, this technique yields superior results to persistence at all three levels and for both forecast intervals. Prediction equations are derived by applying the screening regression technique to atmospheric variables at a network of grid points surrounding a predictand point. Incorporation of predictors, based on perfect prognoses at lower levels, brings about a significant improvement in the results. Some improvement is also noted when a geographical stratification is employed. However, orientation of the grid network with the flow pattern did not result in any substantial improvement.

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